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DISTRIBUTION AND SPECIES RICHNESS OF A FOREST RAPTOR COMMUNITY IN RELATION TO URBANIZATION

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ABSTRACT.—We studied the species richness and distribution of the forest raptor community in a New Jersey watershed in relation to urbanization. Raptors were systematically surveyed using high volume broadcasts of conspecific and heterospecific calls during the breeding season at a total of 81 survey stations. Ten habitat variables relevant to urbanization were measured at each survey station using topographic maps and aerial photographs. Results showed a community composed of 10 species of breeding raptors. *Buteo lineatus, Accipiter gentilis* and *Strix varia* showed a significant avoidance of suburban habitat, whereas *B. jamaicensis* and *Bubo virginianus* had a greater tendency to occupy such areas. Lowland habitat was significantly selected by *S. varia, B. lineatus* and *A. cooperii,* a habitat usually most susceptible to development in the study region. Raptor species richness showed a strong positive correlation ($r = 0.79$, $P < 0.01$) with wilderness area size. No wilderness area less than 1000 ha had more than four raptor species while four to eight species were found in areas from 1000–8000 ha. Utilization of three increasing size classes of wilderness areas showed increasing trends for *B. lineatus, A. gentilis* and *S. varia,* and decreasing trends for *B. jamaicensis* and *Bubo virginianus.*

KEY WORDS: *forest raptors; community; urbanization; forest fragmentation; wilderness; survey.*

Distribución y fertilidad especie de una comunidad bosque de rapaces en relación a urbanización.

RESUMEN.—Nosotros estudiamos la fertilidad de la especie y distribución de una comunidad de rapaces de bosque en una línea divisoria de dos cuencas en New Jersey en relación a urbanización. Los rapaces fueron inspeccionados sistemáticamente usando llamadas de conespecificos y heteroespecificos transmitidas en alto volumen durante la temporada de cría en un total de 81 estaciones de inspección. Diez variables de hábitat pertinente al urbanización fueron medidas en cada estación de inspección usando mapas topográficos y fotografía aérea. Los resultados enseñaron una comunidad compuesta de 10 especie de rapaces en cría. *Buteo lineatus, Accipiter gentilis,* y *Stix varia* mostraron un aversión significante al hábitat suburbio, mientras *B. jamaicensis* y *Bubo virginianus* tuvieron una tendencia mayor para ocupar tales áreas. Hábitat de tierra baja fue sensiblemente escogido por *S. varia, B. lineatus* y *A. cooperii* el hábitat por lo general mas susceptible para el desarrollo en el estudio de la región. La de la especie riquesa de rapaces mostró una correlación fuerte y positiva ($r = 0.79$, $p < 0.01$) con la área del tamaño del bosque. Ningún área de bosque menos de 1000 ha tuvo mas de cuatro especie de rapaces mientras cuatro a ocho especie fueron encontrados en áreas de 1000–8000 ha. La utilización de tres clases aumentando y de diferente tamaño de áreas de bosque mostraron una tendencia de aumento para *B. lineatus, A. gentilis* y *S. varia* y una tendencia decreciente para *B. jamaicensis* y *Bubo virginianus.*
[Traducción de Raúl De La Garza, Jr.]

Raptors are secondary and tertiary consumers so trophic theory suggests that they will be fewer in abundance and lesser in diversity than other breeding bird communities. Factors that tend to promote high species diversity in raptor communities are high prey diversity and high habitat heterogeneity (White 1974). Conversely, forest fragmentation and reduced forest interior tend to reduce raptor community diversity (Thiollay and Meyburg 1988). In Maryland, Robbins et al. (1989) examined the effect of forest area on breeding bird communities and found at least one raptor (the Red-shouldered Hawk, *Buteo lineatus*) was impacted

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by habitat fragmentation and urbanization and qualified to be categorized as an "area-sensitive species." Titus and Mosher (1981) examined natural habitat variables of four sympatric hawk species in Maryland, but urbanization and variables associated with habitat development were not included in their analysis. Nevertheless, Red-shouldered Hawks have been shown to avoid nesting near human dwellings(Bosakowski et al. 1992a) and Northern Goshawks (*Accipiter gentilis*) nest significantly farther from paved roads and human dwellings than randomly-selected sites (Bosakowski and Speiser 1994).

In this study, we examined a wider variety of urbanization variables than previously published for forest raptors and examined their association within a diverse community of breeding raptors. Such data could provide further insight into the preservation and management of viable forest ecosystems for diverse raptor communities rather than using a single species approach.

STUDY AREA

The study was conducted in the Highlands Physiographic Region (Braun 1950) which extends southwest to northeast across the New York-New Jersey border. The study area was part of the Pequannock Watershed, which is owned and operated by the city of Newark, New Jersey. The study area includes approximately 16 100 ha and includes parts of Passaic, Morris and Sussex Counties. This hilly, mostly forested terrain is part of the Eastern Deciduous Forest Biome (Shelford 1963).

Nearly all of the Highlands forests have been previously cut or burned within the last 200 years (Ohmann and Buell 1968, Russell 1981), resulting in largely second growth forest dominated by oaks (*Quercus* spp.) and other subclimax hardwood trees (Buell et al. 1966, Russell 1981). Older forest (>100 years of age) is rare and is typically limited to small remnant stands surrounded by younger forest.

The study area includes some of the last remaining wilderness in the northern half of New Jersey. Residential and commercial development is limited to about 10% of the study area. The remaining land area is composed of a mosaic of submature second growth and mature forest, typically ranging from about 40–80 years of age. About 75% of the forest is deciduous habitat, about 20% consists of hemlock-white pine (*Tsuga canadensis-Pinus strobus*) stands, and 5% is mature conifer plantations. Aquatic habitats include five major reservoirs, several smaller impoundments, beaver (*Castor canadensis*) ponds, marshes, shrub swamps and wooded swamps, the latter occurring in many areas. The study area is periodically thinned, but clear-cutting/burning is not permitted. Since access to these forests is regulated by recreational permits and motorized boats are not permitted on the reservoirs, human disturbance is greatest directly adjacent to some suburban areas.

METHODS

Sampling design. The spatial design of the survey systematically covered the Pequannock Watershed study area with a grid pattern of 81 broadcasting stations, spaced at approximately 1.2 km intervals. The spacing of stations was not used to estimate population size, since this investigation was aimed solely at determining occupancy in different habitat types. The survey stations were plotted on 15 min USGS quadrangle topographic maps of the study area. Four surveys were conducted at each of the 81 broadcasting stations. Surveys were conducted on fair weather days with low wind velocity (<15 km/hr) and no precipitation. The order of sampling of calling stations was different for each of the four surveys due to weather and wind conditions, but stations in the four cardinal quadrants of the study area were worked as equally as possible to avoid regional bias.

Target species. Previous pilot studies (Benzinger et al. 1988, Bosakowski et al. 1989a) revealed 11 potentially breeding raptor species in the study area (excluding Cathartid vultures). To reduce the number of surveys required to survey these 11 species, vocalizations of 2–3 hawk or owl species were broadcast on each survey, resulting in a total of two night surveys for owls and two daytime surveys for hawks. The selection of species for each survey was based on regional nesting phenology (Bull 1964, Bosakowski et al. 1989b, Speiser and Bosakowski 1991, and Bosakowski 1990). Broadcasts were ordered from the smallest to the largest raptor, to avoid potential inhibitory effects of large raptors on the response behavior of smaller species (Call 1978). About half of the raptors responded to heterospecific broadcasts, so every species was actually sampled twice during the day (or night) at all calling stations. Furthermore, some raptors were detected by visual observations or calling prior to broadcasts on either survey, regardless of the species that were broadcast.

Broadcast vocalizations and equipment. Eastern Screech-owl (*Otus asio*), Great Horned Owl (*Bubo virginianus*), Northern Saw-whet Owl (*Aegolius acadicus*), Barred Owl (*Strix varia*), Red-shouldered Hawk, Red-tailed Hawk (*Buteo jamaicensis*) and Broad-winged Hawk (*Buteo platypterus*) vocalizations were obtained from the National Geographic Society guide to Bird Songs (Evatone Soundsheets, Inc., Clearwater, FL, 1983). Northern Goshawk, Sharp-shinned Hawk (*Accipiter striatus*) and Long-eared Owl (*Asio otus*) vocalizations were from the Peterson Field Guide records, Cornell University, Laboratory of Ornithology. A Cooper's Hawk (*Accipiter cooperi*) tape of the female alarm call was obtained from R.N. Rosenfield (Rosenfield et al. 1985).

Tapes were broadcast from a Contec portable stereo cassette tapedeck (Model V83, Japan) rated at 10 watt output with two removable speakers. The units were powered by 8 "D" cell batteries. Cassette tapes (normal bias) were broadcast at a standard volume setting, approximately 95% of full capacity, but without detectable distortion. The speakers were high fidelity, each containing a woofer and tweeter component for more accurate sound replication of calls. The two speakers were mounted back-to-back to provide bidirectional broadcasting of vocalizations at all times.

Field protocol. Two surveys were conducted at night

for the five target owl species. These surveys began at least ½ hr after sunset and were terminated by 0100 H the following morning. The first owl survey was conducted from 21 March 1989–16 April 1989 for Eastern Screech-owls, Long-eared Owls, and Great Horned Owls. Species on the second owl survey, conducted from 16 April–19 May 1989, included the Northern Saw-whet Owl and Barred Owl. Hawk surveys were conducted from at least 2 hr after sunrise to no later than 2 hr before sunset. Species included on the first hawk survey conducted from 7 April–4 May 1989 included the Red-shouldered Hawk, Northern Goshawk, and Red-tailed Hawk. The second hawk survey from 18 May–20 June 1989 included the Sharp-shinned Hawk, Cooper's Hawk, and Broad-winged Hawk.

On each survey, tape-recorded vocalizations of three raptor species were played during an 18-min period. Vocalizations of each species were recorded on cassette tape for a 3-min period followed by a 3-min period of silence. The silent period served a dual function as a listening/watching period for vocal or visual responses of raptors and also as a refractory period prior to broadcasts of the next raptor species. The double speakers were hung on low tree branches about 1.5 m above ground during broadcasts.

Macrohabitat measurements. To measure habitat at the 81 calling stations, their location was plotted on topographic maps and their position noted on aerial photographs (1:8000) taken during the winter of 1982. Habitat at each calling station was quantified in a 300 m radius circle centered on the calling station. This distance was chosen as representative habitat of the calling station as all raptors were detected within this distance and most were detected within 100 m. On aerial photographs, a dot-grid overlay was used to quantify the suburban area within the 300 m radius circle. To measure the length of paved roads and forest edge within the habitat circles, we overlayed them with a fine thread, then the thread was straightened and measured. Forest edge can be considered as any abrupt change (Small and Hunter 1989) to open habitat (e.g., field, marsh, river or lake) that are easily discernable on the aerial photographs. We measured distances to forest openings (>0.5 ha), paved roads, human habitation and wetlands (>0.5 ha) from aerial photographs using a metric ruler with a mm scale. Topographic maps were used to calculate slope (rise in elevation over 300 m baseline). For the purposes of this paper, "wilderness" was defined according to a standard operational definition supplied by Webster's Dictionary as "any uninhabited, uncultivated region." Wilderness area was calculated as the total area of contiguous, uncultivated, uninhabited habitats bounded by paved roads and/or housing developments.

Statistical analysis. A total of 10 habitat variables relevant to urbanization were used to describe the 81 calling stations. Each raptor species had a unique set of stations where they were recorded and these data sets were used to calculate habitat means and standard deviations. In order to increase the sample size for Eastern Screech-owl ($N = 3$) and Northern Goshawk ($N = 2$), two screech-owl sightings and three goshawk nests from previous years were added to the data set. These additional raptor locations occurred in the mid- to late eighties and fell well within five of the 81 habitat circles described. No additional sites were known for the Long-eared Owl which was found at only two sites, or the Sharp-shinned Hawk which was found at one site, so they were dropped from any habitat analyses.

Table 1. Species richness values for breeding raptor communities studied in North America.

STUDY	AREA (HA)	NO. OF SPECIES
New Jersey (this study)	16,100	10
Utah (Smith and Murphy 1973)	20,700	11
Wyoming (Craighead and Craighead 1956)	3,100	10
Michigan (Craighead and Craighead 1956)	9,600	7
Idaho (BLM 1979)	53,200	15

Each species was compared to the set of stations which did not have any raptor detections during the study (unoccupied habitat, $N = 20$) to provide a measure of habitat selection. For statistical comparison, we used a nonparametric test (Mann-Whitney U-test) since some of the data were percentages or nonnormal in distribution (Zar 1974). Species richness was determined for all wilderness areas with four or more survey stations and a logistic regression curve was calculated (Excel Software, Microsoft Corp., Redmond, WA, Version 5.0) to test the strength of the relationship. To detect area relationships for individual species, wilderness areas were grouped into three size class categories (0–1000, 1000–2000 and 2000–8000 ha) for all broadcast stations. The percentage of occupied stations by a species in each size class (% usage) was subtracted from the percentage of all stations sampled (% availability) to determine habitat utilization (Johnson 1980) for each wilderness area size class. Usage is said to be selective if resources are used disproportionately to their availability (Johnson 1980). Proportions in each category were tested for increasing or decreasing trends in relation to wilderness area size using an Armitage (1955) proportion trend test.

RESULTS AND DISCUSSION

Species Richness of the Raptor Community. We compared raptor species richness of the New Jersey raptor community with studies of other raptor communities (Table 1). Of these studies, the lowest species richness was found in Michigan (Craighead and Craighead 1956) which was mostly farmland (11% wooded). New Jersey forestland and the spruce-fir-pine slopes and sagebrush benches in the Snake River of Wyoming (Craighead and Craighead 1956) had slightly higher richness but both were surpassed by Utah scrub juniper desert (Smith and Murphy 1973). Highest species richness was reported for Snake River Canyon in Idaho

Table 2. Urbanization habitat variables for sites occupied by forest raptors in a northern New Jersey watershed. Top number represents the mean and bottom number represents the SD (* = $P < 0.05$, + = $P < 0.10$). Sample size for each species given in parenthesis. GHOW = Great Horned Owl, BAOW = Barred Owl, ESOW = Eastern Screech-owl, RTHA = Red-tailed Hawk, RSHA = Red-shouldered Hawk, BWHA = Broad-winged Hawk, COHA = Cooper's Hawk, NOGO = Northern Goshawk.

VARIABLE	GHOW (16)	BAOW (27)	ESOW (5)	RTHA (22)	RSHA (9)	BWHA (16)	COHA (10)	NOGO (5)	UNOCCUPIED HABITAT (20)
Distance to Human Habitation (m)	426.6 325.9	671.9* 488.0	778.0 659.4	477.3 411.6	888.9* 569.7	769.4 704.4	651.5 672.0	676.0+ 533.5	505.0 496.2
Number of Houses/Bldgs. (#)	4.19 7.30	1.26* 3.14	0.60 0.89	3.32 5.55	0* 0	3.06 4.35	1.20 2.25	0* 0	2.35 4.35
Suburban Area (%)	2.7 4.1	1.0+ 2.5	0.2 0.3	2.4 3.7	0* 0	2.5 3.6	0.9 1.9	0* 0	1.5 2.4
Distance to Paved Road (m)	292.8 258.0	468.0 465.6	458.0 393.9	406.6 345.9	546.1 549.9	343.8 293.5	259.0 141.0	482.0 243.0	343.8 294.4
Road Mileage (m)	404.7 620.2	299.4 321.4	64.0 143.1	367.5 528.7	206.7 226.3	269.4 330.5	352.5 380.5	78.0 174.4	268.4 294.1
Edge Length (m)	623.7 632.7	370.0 524.2	652.0 536.6	595.9 617.6	492.2 618.8	374.1 374.9	656.5 420.5	369.0 550.1	467.0 526.6
Distance to Wetland (m)	563.1 518.2	197.0+ 247.9	662.0 581.8	442.0 585.0	62.2* 49.7	360.3 377.8	252.0 203.1	164.0 207.5	369.8 333.4
Distance to Forest Opening (m)	195.0 237.3	199.7 206.2	197.0 261.5	163.9 192.2	80.6* 91.4	141.6 148.1	112.0+ 109.6	147.0 141.3	240.2 195.4
Slope (%)	6.5 4.4	6.1 4.8	10.0 4.9	6.8 4.7	5.1+ 5.3	6.9 6.3	4.4* 4.1	6.8 6.7	8.0 5.5
Wilderness Area (ha)	2291.2 2731.4	3766.9 3164.4	5094.0 3543.4	2498.2 2971.8	4388.9 3179.1	3144.0 3204.8	2271.6 2181.3	5278.0 3320.5	2729.5 2636.0

(BLM 1979) with its vertical cliffs and sagebrush desert, probably reflecting the high structural habitat diversity as a result of vertical and horizontal habitat partitioning. Overall, cultivated land of Michigan (circa 1950s farming techniques) appeared to slightly reduce raptor diversity and abundance compared to contiguous forestland in New Jersey.

Urbanization and Forest Fragmentation. Urbanization and its ultimate effect in fragmenting forests into smaller wilderness areas is an unnatural factor which reduces raptor abundance and diversity. Robbins (1979) noted the disappearance of several nesting bird species including the Broad-winged Hawk after 30 yr of severe fragmentation. In our study area, the proximity of human habitation showed marked differences in the habitat suitability for several forest raptors. The Red-shouldered Hawk was most sensitive to human disturbance and it occupied sites significantly further from human habitation than unoccupied habitat and it showed a complete lack of suburban habitat within the 300 m radius habitat circles examined (Table 2). The Northern Goshawk had the second largest distance to human habitation ($P < 0.10$) and similarly showed a significant lack of suburban habitat within the 300 m radius habitat circles examined. Additional data from 16 Northern Gos-

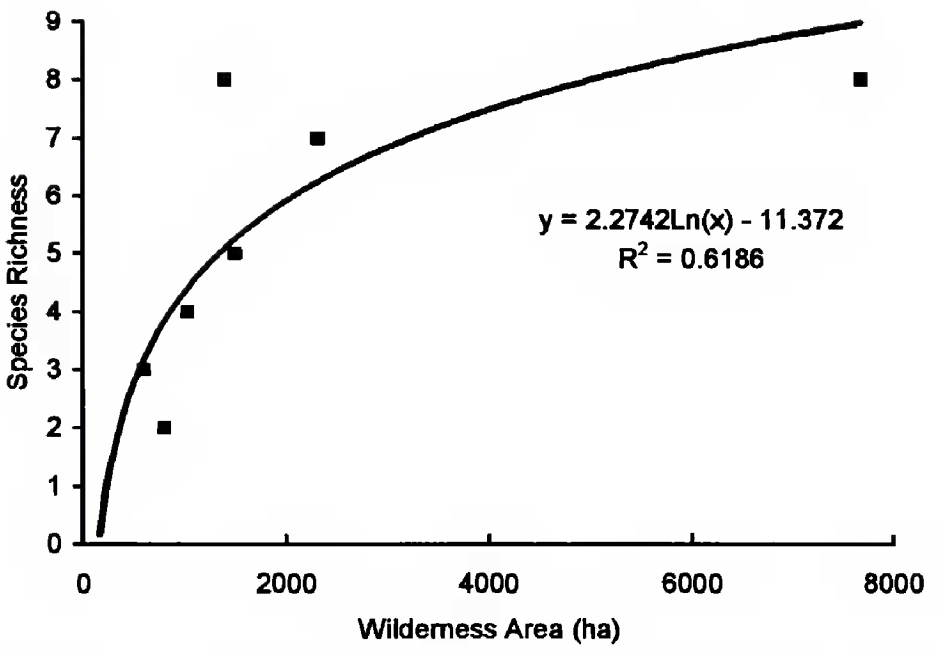

Figure 1. Species richness of forest raptors with respect to seven wilderness areas of varying size. Curve represents best-fit logistic regression function.

hawk nest sites in the study region also showed that the species nests further from human habitation and paved roads than expected (Bosakowski and Speiser 1994). In the study region, Northern Goshawk nests were significantly farther from human habitation than were Cooper's Hawk nests (Bosakowski et al. 1992c) or Red-tailed Hawk nests (Speiser and Bosakowski 1988). The Barred Owl was similar to the Red-shouldered Hawk and Northern Goshawk, occupying sites that were significantly farther from human habitation, with significantly fewer houses, and a tendency for less suburban habitat area ($P < 0.10$).

With regard to wetlands, the Red-shouldered Hawk occupied areas significantly closer to wetlands which resulted in a significantly lower slope percentage as well as a significantly closer distance to forest openings. The Barred Owl also had a tendency to be closer to wetlands ($P < 0.10$). The Cooper's Hawk occupied sites with significantly lower slope percentages and was often closer to forest openings ($P < 0.10$), but not necessarily due to a preference for wetlands since it often used suburban forest edge as well. Overall, these three lowland species had a greater vulnerability to development pressures as valley bottoms and flat terrain are generally the first areas targeted for roads, houses and commercial buildings (Tiner 1985).

Distance to paved roads, road mileage, edge length and wilderness area did not show any significant differences among any species compared to unoccupied habitat. Four species, Great horned Owl, Red-tailed Hawk, Eastern Screech-owl and Broad-winged Hawk did not have any variables that were significantly different from unoccupied habitat, suggesting that they were less sensitive to urbanization.

Forest Area Relationships. Area-sensitive species respond negatively to decreasing forest size and show predictable declines or absence as the area of the forest shrinks (Robbins 1979, Ambuel and Temple 1983, Robbins et al. 1989). Within our study area we found a strong correlation ($r = 0.79$, $P < 0.01$) for species richness of forest raptors and increasing size of wilderness areas (Fig. 1). This is likely the result of the inclusion of area-sensitive species in large wilderness areas and their exclusion in smaller forest fragments. No area less than 1000 ha had more than four raptor species while 4–8 species were found in areas from 1000–8000 ha in size. Thiollay and Meyburg (1988) also noted a positive correlation between the size of reserves and the abundance index of diurnal raptors (Falconiformes) on the Island of Java.

When wilderness areas were grouped into size classes, several distinct trends emerged among the species. We calculated percent utilization of three wilderness area size classes and determined the probability of increasing or decreasing trends for raptors. Several species revealed increasing trends with increasing wilderness area size (Red-shouldered Hawk, $P = 0.97$; Northern Goshawk, $P = 0.84$; and Barred Owl, $P = 0.82$), whereas several species revealed decreasing trends (Red-tailed Hawk, $P = 0.95$ and Great Horned Owl, $P = 0.85$, Fig. 2). Craighead and Craighead (1956) noted

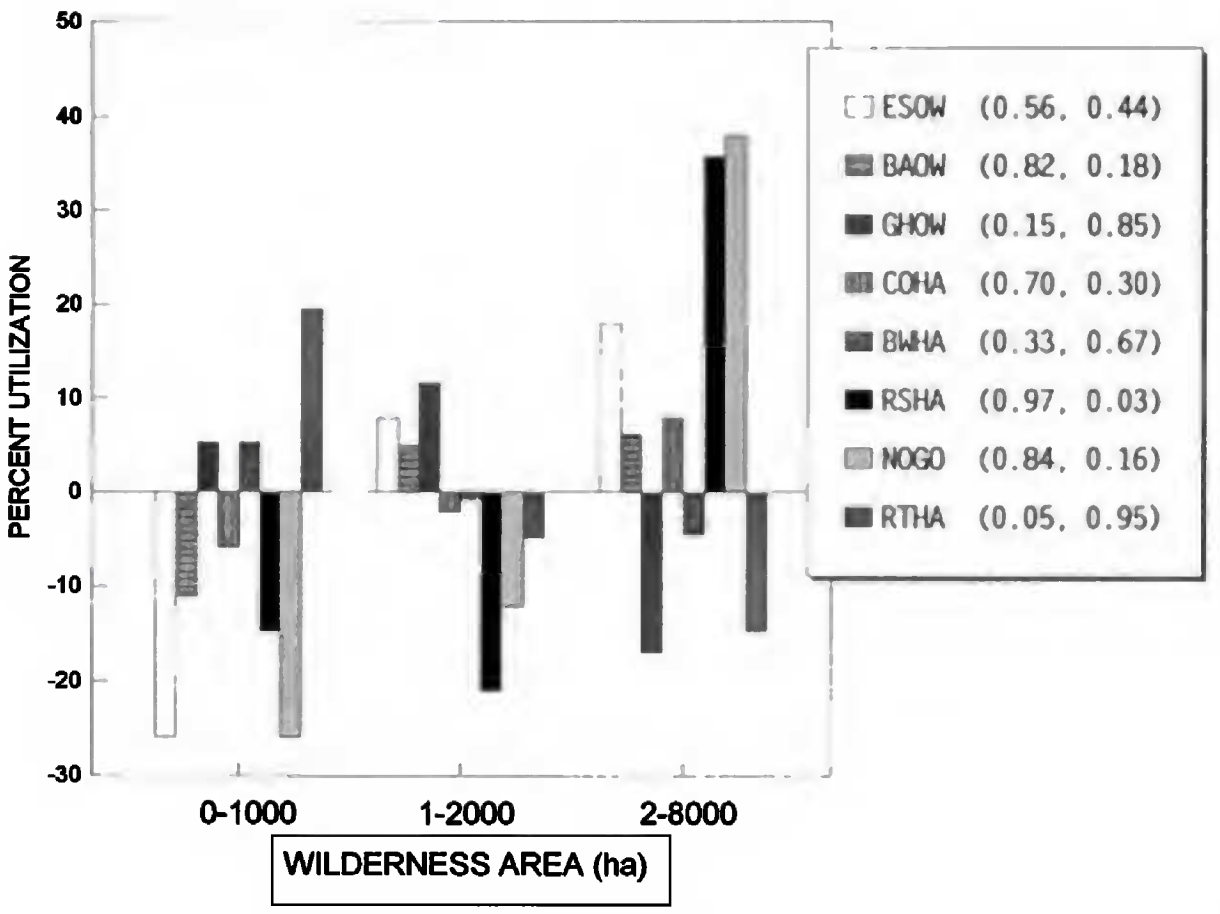

Figure 2. Relative utilization (use-availability) of different wilderness area size classes for eight sympatric forest raptor species (see Table 2 for species acronyms). Numbers in parentheses represent probability of species increasing and decreasing (I, D) in relation to wilderness area size (Proportion Trend Test—Armitage 1955).

that Red-tailed Hawks and Great Horned Owls were generalist predators and the results of this study indicate that they clearly benefit from forest fragmentation and urbanization (at least to the extent found in the study area). On the other hand, Red-shouldered Hawks, Northern Goshawks and Barred Owls usually prefer extensive remote areas of deep woods (Bosakowski 1989, Bosakowski et al. 1992a, Bosakowski and Speiser 1994).

The northern half of our study area was virtually all wilderness and contained all 10 species. However, the southern half had nearly all of the suburban areas and a four-lane highway, and was missing three species (Northern Goshawk, Sharp-shinned Hawk and Red-shouldered Hawk). Results of this study predict the expansion of dominant, disturbance-tolerant Great Horned Owls and Red-tailed Hawks after forest fragmentation, and a reduction in raptor diversity.

A decrease in forest area can result in decreased bird species diversity (Lovejoy et al. 1986), disturbance to species in adjoining wetlands, reduced buffering against human disturbance and increased predation (Chasko and Gates 1982, Yahner 1988). It is also becoming increasingly clear that "edge effect" is beneficial to only a limited number of wildlife species and, by and large, it has a strong negative impact on other members of forest communities (Robbins 1979, Wilcove et al. 1986, Yahner 1988, Robbins et al. 1989). For tropical rainforests, Thiollay (1984) found that raptors are among the first species to disappear in the process of human population growth and exploitation and are thus suitable indicators of habitat disturbance. The situation appears to be similar for temperate forests disrupted by urbanization and agriculture (Craighead and Craighead 1956).

Large raptor communities are needed as population reserves to maintain genetic diversity and to provide constant recruitment to marginal habitats (White 1974, Wilcove 1987). Results of this study suggest that only large wilderness areas (2000–8000 ha) can provide the full diversity of forest raptors necessary to stock marginal habitats. Until other data on reserve size become available, the present data could have useful management implications for conservation of Northeast forest raptors, either by regulating development and recreation, or deciding how large an area should be set aside for future reserves. In addition, further research will be needed to determine the number and distance of other reserves (Shaffer 1985, Hunter 1990) necessary to support a viable population network for each species (Wilcove 1987).

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